Volume 32 August, 1946 *Number 8*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

35TH ANNIVERSARY ISSUE

Hydraulic Oils
for
Industrial Equipment

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

1911 35 YEARS OF 1946
Lubrication

With this issue, the magazine "Lubrication" celebrates its 35th birthday. Except for an 18-month period during World War I, it has been published continuously since August 1911 — a real "old timer" as company-sponsored publications go.

In 1911 there was a real need for "a technical publication devoted to the selection and use of lubricants," and "Lubrication" came into being to fill that need. Its purpose then, as now, was to present unbiased viewpoints on all of the various phases of lubrication.

GROWTH AND DEVELOPMENT

Writing in October 1913, Harry Tipper, Advertising Manager of The Texas Company and the first editor of "Lubrication," re-stated the magazine's aims and purposes, and went on to say:

> "This book, first published for the employes of The Texas Company, found its way outside, and by degrees, requests became so insistent and numerous as to make it necessary to add materially to its scope . . . it has been favorably received wherever it has gone and we feel that its progress is sufficient evidence of its value to justify its continued publication and circulation among those interested."

For the past 15 years, the request circulation of "Lubrication" has been between forty and forty-five thousand, which is the best indication that "Lubrication" has lived up to the high standards set for it. "Lubrication" is on file in leading public libraries throughout the country, in technical schools and in engineering departments of every branch of industry. Copies frequently turn up in unusual places, one being discovered, for instance, in the engine room of a submarine.

First issued as a quarterly, "Lubrication" began monthly publication in November 1915, and about a year later the editorship was taken over by Dr. L. H. Canfield, The Texas Company's Supervisor of Education, who held the post until the wartime suspension of publication in October 1918.

IMPROVED FORMAT

When "Lubrication" resumed publication in May 1920, it was in a new format and under the editorial guidance of Dr. Raymond Haskell, Industrial Sales Engineer, who carried on until the present editor, Allen F. Brewer, took over in 1922.

Page size of the early "Lubrication" was about a third less than it is today, and illustrations were few. In fact, the first two issues contained no illustrations at all. Succeeding issues carried some line drawings, and the halftone illustrations that are used so profusely in "Lubrication" today made their initial appearance in 1913; currently many of these illustrations are in color. The method of handling subject matter, too, has changed and improved. The first issues of "Lubrication" carried four or five short articles on widely different lubrication topics, while the usual practice today is to devote each issue to a single subject — the lubrication problems of one industry, for example, or the ramifications of one particular lubrication or fuel problem of wide interest. By-lines, which were frequent in the beginning, no longer are used since today's articles represent the thinking and experience of several individuals, experts in their respective fields.

POLICIES CONTINUED

An interesting indication of the ever-growing importance of lubrication in our modern world, and the need for unbiased sources of information about lubricants and lubrication procedures, is the fact that "Lubrication" was published without interruption all through World War II.

As "Lubrication" enters its 36th year, The Texas Company is happy once more to re-affirm its policies and purposes, and to express the hope that this publication may continue to render ever greater service to its readers.

ALLEN F. BREWER

EDITOR

Allen F. Brewer, the present editor (in reality Editor-in-Chief) of "Lubrication", has held that post since July, 1922. His able service to this publication thus spans all but a year of a quarter-century. The well-ordered and well-written pages of "Lubrication" itself each month are the highest testimonial to his capabilities, talents, and enthusiasm for his work, to which he has brought an interesting background of training and experience. Many of the articles are prepared by him; others are prepared by experts in their respective fields, in order to give the reader the most authoritative information on the theory and application of petroleum fuels and lubricants.

Allen Brewer was graduated from Massachusetts Institute of Technology in 1914, in Mining and Metallurgy. He then worked with the New Jersey State Board of Public Utility Commissioners as inspector and evaluator of power plants and utility properties until 1917; and joined the American International Shipbuilding Corporation just before this country entered World War I.

Early in 1918, Mr. Brewer enlisted in the U. S. Navy and was promptly detailed to the United States Navy Steam Engineering School at Stevens Institute of Technology, from which he was commissioned with the rank of Ensign. He served on active sea duty in European waters.

From the Navy, Mr. Brewer came to The Texas Company in June, 1919, as Fuel Oil Engineer with the Export Department. A year later he was transferred to the Refining Department and assigned to Port Arthur, Texas, where he subsequently became Plant Lubrication Engineer. In July, 1922, as a member of the Sales Department, he was brought to New York and took over the editorship of "Lubrication". His present status with The Texas Company, which he has held since 1928, is Technologist (Engineering) with the Technical and Research Division of the Refining Department.

"Who's Who In Engineering" lists Allen Brewer as a member of the American Society of Refrigeration Engineers, and Association of Iron and Steel Engineers. He is also a member of the American Society of Mechanical Engineers, the American Society of Lubrication Engineers and is a licensed engineer in the States of New York, New Jersey and Pennsylvania. For many years he held a marine engineer's license. His by-line has appeared over many articles and papers on various aspects of lubrication which have been printed in a wide list of trade and technical publications.

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

Vol. XXXII August, 1946 No. 8

Hydraulic Oils for Industrial Equipment

THE history of power is fantastic in its recording of the ways and means devised to relieve man of manual labor. The Egyptians were probably the first to adopt any substitute for man or animal power. They took advantage of the wind by means of primitive sailboats on the river Nile. Later they developed waterwheels and treadmills to raise water from this same river for the purpose of irrigating adjoining fields.

It was not until centuries later, in fact about 1650, that further serious thought was given to the use of water as a source of power or power transmission. About this time Pascal discovered the fundamental laws of physics upon which all modern hydraulic systems are governed. Unfortunately, Pascal never put this new knowledge to practical use and the history of hydraulics had to mark time until 1795, when a man named Joseph Bramah developed the first hydraulically operated press, using water for power transmission.

If either of these gentlemen were alive today they would be amazed at the progress which has taken place in hydraulics since their early discoveries. Today, there is hardly a product made which at some point during its manufacture does not involve the use of hydraulics.

WHY HYDRAULICS

Why hydraulics? — Because hydraulics offer a relatively simple method of applying large forces with an accuracy of control that is astounding. Hydraulic equipment, as available today, is so versatile that it is used to control the motion of machine tool parts with an accuracy measured in ten thousandth of an inch. Conversely, hydraulics are as easily applied to huge presses, the working pressures of which are measured in tons.

Hydraulic power is distinctive because of its flexibility, thus establishing a definite place for its usage in many industries. Hydraulic power, however, is not distinctive as being the only means available for the transmission and control of power.

The design engineer can choose between mechanical, pneumatic, electrical, hydraulic, or the more recently developed electronic methods of power control and transmission. Each of these methods has a definite field of application in industry. Mechanical and electrical methods are used widely in equipment where it is convenient to locate the source of power and its control close to the work being done. Hydraulic, pneumatic and electronic controls have the advantage of flexibility in the location of the control equipment and, hydraulics in addition, have the added advantage that the amount of power transmitted is almost unlimited.

Some of the other features of hydraulic power are:

1. Simplicity in design.
2. Extreme flexibility of location.
3. Systems can be made completely automatic to control a sequence of operations.
4. Extreme accuracy of control.
5. Wide variety of speeds and pressures.
6. Reduction of wear on moving parts by: (1) resiliency of operation which minimizes shock loads, (2) automatic release of pressure at overload, and (3) absence of vibration.
7. Economical to operate.

The development of automatic machines, the desire for labor-saving devices, streamlining, the requirement for remote control, and the need for a compact source of accurately controlled power have all contributed to the popularity of hydraulics. Although hydraulics are widely used today, the interest in this field is so intense that the future will see a much greater diversity of application of this important method of power control.

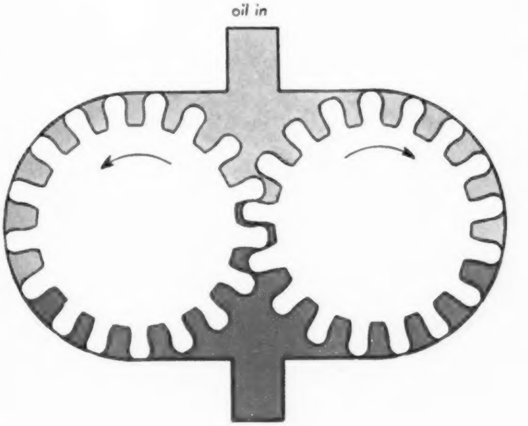
Obviously, such a diversity of uses for hydraulics necessitates special consideration of properties of the fluid used. Aircraft, for example, require the use of special power transmission fluids not normally needed by Industry. This article is confined to the type of hydraulic oils generally required by Industry and particularly for power transmissions in:

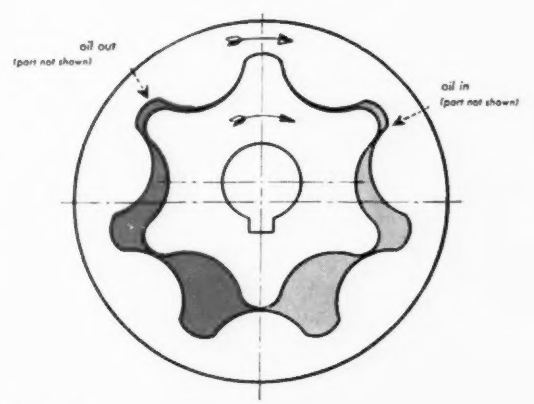
- Metal Working Equipment
- Construction Equipment
- Plastic Equipment
- Marine Equipment
- Presses
- Printing Equipment
- Paper Making Equipment
- Rubber Making Equipment
- Textile Equipment

HYDRAULIC SYSTEMS

Simple hydraulic systems consist essentially of four units; namely, a reservoir to supply oil, a pump to generate flow of the fluid under pressure, a selector control valve to direct the flow and, finally, an actuating cylinder in which fluid pressure is converted to mechanical energy. Such a system may be even further simplified by using a two way variable delivery pump which eliminates the need of a directional control valve.

Systems of the above types are used on some hydraulically operated presses, lifts, jacks, and other simple mechanisms, but most systems are much more complex.





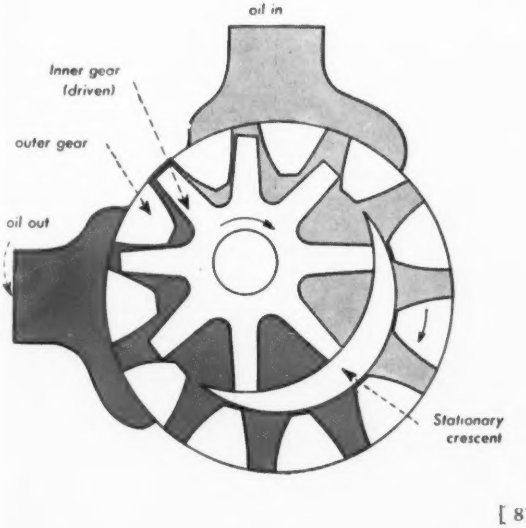


Figure 1

GEAR TYPE PUMPS

Gear pumps operate on the very simple principle that as gears revolve, oil trapped in between the gear teeth and the housing is carried from the suction side to the discharge side of the pump. Oil from the high pressure side is prevented from returning to the low pressure side by the close meshing of the two gears.

The maximum pressure generated by gear pumps depends entirely upon the closeness of the fit between the gears and housing. Pumps of this type have been used to generate pressures as high as 1000 lbs. but normally they operate at 200-300 pounds per square inch.

These pumps when driven at a given speed are capable of discharging only a constant volume of oil.

The heart of any hydraulic system is its pump, and a variety of these are used. Basically, pumps can be classified into two groups: (1) Constant delivery when running at a given speed, and (2) Variable delivery when running at a given speed.

Constant delivery pumps operating at a constant speed discharge a constant volume of oil at a given pressure. Systems using such a pump are relatively inexpensive, and usually operate at pressures as low as 200-300 pounds but seldom above 2,000 pounds per sq. inch. Systems incorporating constant delivery pumps are often used on machine tools, such as saws, light surface grinders, and small shapers; also on lifts, construction machinery, etc.

Variable delivery pumps are usually run at constant speed, and are so designed that the volume output can be easily varied from zero to maximum in either direction. If suitable valves are incorporated, the operating pressure can also be varied. Such systems are found where motions must be accurately controlled, where variation in flow of the oil is great, or where high oil pressures are required.

A specific machine may contain either of the above types of hydraulic systems or both may be on one machine. In some instances, they may be combined into a single system to assume, for example, alternate control during certain portions of the operating cycle.

Pumps may be further divided into groups based upon the method used to create pressure. Practically all hydraulic pumps fall within three classifications of design; namely, gear, vane or piston types and a description of how each functions is given in Figures 1, 2 and 3. All three types may be used in constant volume systems, whereas, only vane and piston pumps are used in variable volume systems.

Hydraulic pumps and valves are precision made instruments in every sense of the word. Careful selection of metals and fine workmanship are necessary requirements in the production of pumps and valves capable of generating and controlling pressures encountered in hydraulic systems.

The efficiency of a hydraulic pump depends upon the absence of wear throughout its life. Abnormal wear, for example, causes increased slippage of the oil, resulting in power loss, reduced output, and increased operating temperature.

Clearances in pumps are extremely small and even small amounts of gum or sludge from the oil, or contaminants such as rust or dust can cause trouble just as in a ball or roller bearing.

Flow control, metering, sequence, pressure reducing and other types of valves used in controlling the flow of oil from the pump to the actuating cylinders are also made with very close

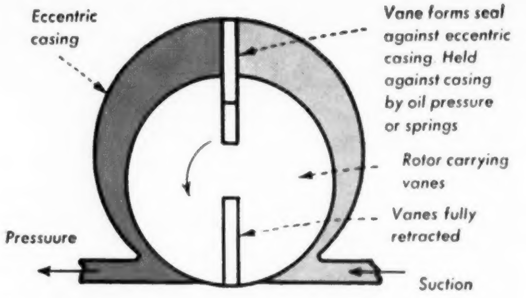


Figure 2

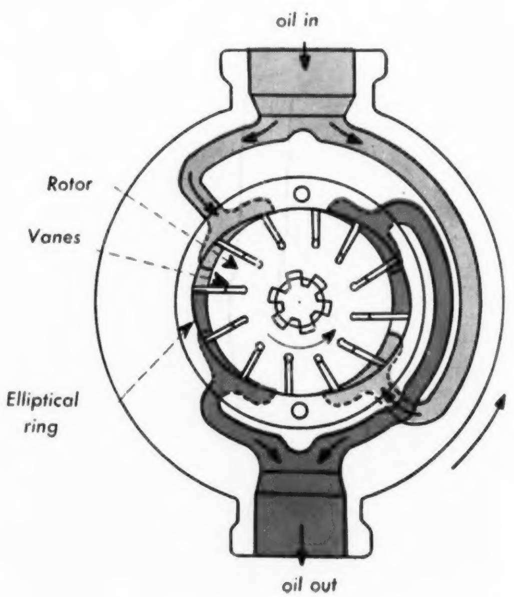
VANE TYPE PUMPS

The rotor of a vane type pump has on its circumference a number of equally spaced slots in each of which is a free moving vane or blade. As the rotor revolves the vanes are thrust against the outer ring forming an effective seal.

Two general methods are used to obtain pumping action. In one the rotor may be in the middle of an elliptical ring (see the illustration below) and as the pump rotates the oil is compressed and finally discharged by the decrease in clearance between the rotor and ring. Pumps of this type deliver a constant volume of oil at a given speed.

In the second the ring is perfectly round and the rotor is located eccentrically with respect to the ring (see the above illustration). This type of pump can be made to discharge a variable volume of oil while running at constant speed simply by adjusting the degree of eccentricity. This can be done manually or automatically by a suitable control outside the pump housing.

Both the vanes and the ring are made of hardened steel. These pumps do not lose their volumetric efficiency as rapidly as gear pumps because of the fact that vane wear is compensated for by the outward movement of the vanes.



tolerances to give precision control. These too, must be protected from abnormal wear and the presence of contaminants.

Hydraulic equipment manufacturers have done an excellent job in developing systems which will give trouble-free operation over long periods of time, but even the best of equipment will not continue to function properly if the fluid installed in the system is not of proper quality and the correct grade. Petroleum refiners have met this challenge by developing oils specifically designed for use in hydraulic systems.

HIGH QUALITY HYDRAULIC OILS ARE ECONOMICAL

Many factors contribute to the need of special care in selecting hydraulic oils. Some of the factors encountered in hydraulic systems such as rusting, contamination, etc., have necessitated the development of oils having certain properties which result in the elimination, or at least minimizing, of the adverse effects these factors have on the continued smooth operation of the hydraulic system.

Some of the more important factors which can cause erratic motion of hydraulically operated equipment or even complete stoppage are discussed in the following paragraphs.

Gum or Sludge Formed as the Result of Oxidation

Oil in hydraulic systems is subjected to violent agitation each time it passes through pump and valve mechanisms; and in cases where reservoirs on equipment are comparatively small, the lubricant does not have much chance to rest between cycles. Continued severe agitation contributes to oil oxidation.

Temperature, too, is a contributing factor to oxidation. For example, it is well known that, with all other factors constant, rates of reaction double for every 18°F. increase in temperature. Below about 140°F., the rate of oxidation of oil is very slow if pressure, agitation, and catalysts are not contributing factors. Above this temperature, rate of oxidation increases to such an extent that it becomes an important factor in the life of the oil, and for this reason it is desirable that hydraulic systems operate at as low an overall temperature as is practical. The average temperature of oil in a hydraulic system is not a true indication of the highest temperature to be found. In the pump, for example, changes in pressure from atmospheric to several thousands of pounds cause momentary heating of the oil to a much higher temperature.

A third factor contributing to oxidation of oils is pressure. As pressure is raised there is a correspond-

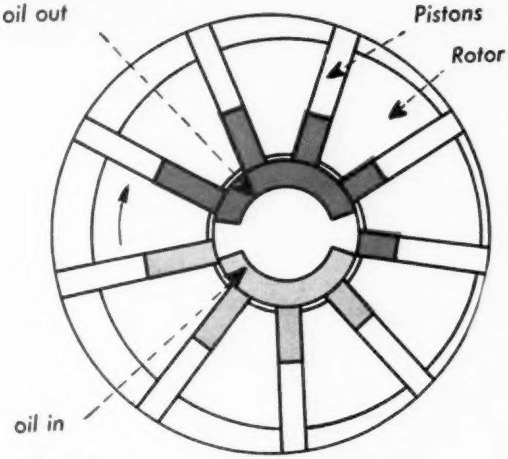


Figure 3

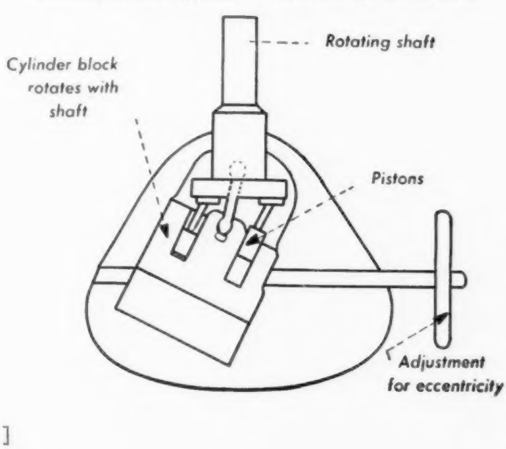
PISTON TYPE PUMPS

There are many variations of piston type pumps on the market today but generally all are fundamentally based on the radial piston type pump illustrated above and the axial piston type shown below.

Both of these types can be operated to give a constant delivery but generally they are so made as to give a variable discharge of oil when running at constant speed. Piston type pumps can be made to generate pressures as high as 10,000 lbs. per square inch.

Axial piston type pumps contain a cylinder block assembly in which the pistons are located equally around the cylinder block axis and the cylinder bores are parallel to the axis. The cylinder block is linked to the driving mechanism in such a way that the driving mechanism and cylinder block rotate at the same speed. The pistons are driven through connecting rods attached to the driving plate by ball and socket joints, or by a wobbler plate. The angle between the axes of the cylinder block and the drive shaft determines the volume output.

Radial piston pumps consist of a rotating cylinder block containing radial cylinders and an outer casing which pistons (or the cylinders, depending upon the design) are in constant contact with. By varying the eccentricity of the rotating cylinder blocks with respect to the outer casing, the amount of oil pumped is controlled. If the two are concentric, no oil is pumped and as the degree of eccentricity is increased, so is the volume of oil pumped. Shifting the degree of eccentricity in the opposite direction will reverse the flow.



ing mild increase in the rate of oxidation. In addition, as pressure becomes higher the rate at which oil passes through small clearances is increased, thus causing a more severe "shearing action" of the oil. This, too, is conducive to oxidation.

Oxidation of oil is also catalyzed by metals, such as copper, bronze, brass and steel; also by water, dust, rust and other contaminants.

Each of the factors discussed above — agitation, temperature, pressure and catalysts — when present by themselves exerts its individual effect on the deterioration of oil. When all are present, as they are in most hydraulic systems, the cumulative effect may be sufficient to cause serious oxidation of oils. Manufacturers of hydraulic equipment and oil suppliers, alike, recommend therefore, that only oils highly resistant to oxidation be used.

If oils highly resistant to oxidation are used and accepted maintenance practices are followed in the care of the oil, oxidation will seldom, if ever, proceed to the extent that gumming or sludging will occur. In some instances, where oils of poor quality have been used, or where abnormal operating conditions prevailed, oxidation of the oil has proceeded so rapidly that sludging necessitated shut down of such systems after only a week or two of operation. Obviously, systems so sludged-up must be completely dismantled and mechanically cleaned — an expensive process, particularly when the non-productive downtime of the machine is taken into account.

Oxidation need not proceed to the stage where sludge is formed, to be harmful. A small quantity of gummy material, for example, may cause the sticking of closely fitted parts in the pump and valves in the system. Small amounts of sludge, or gum, can easily plug the orifices found in various valves and pumps. If these are plugged, the smooth action of the entire system becomes erratic, necessitating shut-down.

Oxidation of oils in hydraulic systems may be minimized by three methods:

1. Use of oils which are so refined that they are resistant to oxidation, and, in addition, inhibited against oxidation by the incorporation of certain additives.
2. Use of systems in which one or more of the factors contributing to oxidation are minimized.
3. Proper maintenance (including established drain periods), cleanliness and prevention of contaminants entering the system.

Rust

Undoubtedly, more equipment made of ferrous metals is destroyed by rust than by any other single factor. Hydraulic systems are by no means exempt.

Rusting occurs in a hydraulic system because moisture is present due to condensation from air entering through leaks on the intake side of pumps, breathing of air through vents in reservoirs, contamination, etc. Such rust may not look serious, but it is if one considers that only one or two flakes of rust passing through precision made pumps and valves can so scratch surfaces that the efficiency of these parts is reduced. Pumps operating at extremely high pressures should be carefully protected against rust, for a scratch on pistons, for example, may permit an excessive amount of slippage — just as an automobile engine loses compression with scored cylinders.

The petroleum chemist has provided a means of preventing rust formation by incorporating suitable inhibitors which "plate out" on metal parts, keeping moisture away from the surface. This is a far more practical means for rust control than complete elimination of all moisture from the system, an expensive and unreliable procedure.

Contamination

Hydraulic systems, even though supposedly tightly closed and built to operate at high pressures, are not all necessarily immune to contamination during operation. Impurities also find their way into new systems or while repairs are being made if extreme care is not exercised.

Many kinds of contaminants may cause deposit formation in a system. Some of these are cutting oils and coolants leaking into the system; grease gaining entry through packing glands, or on piston rods; atmospheric dust through the breather; surface paints which are not resistant to hot oil; indiscriminately used rustproofing preparations, gasket cements, and pipe sealers; to mention the more prominent types.

The petroleum refiner has done his best to furnish oils with exceptionally high chemical stability to resist the action of contaminants. Even so, the safest course is to follow a proper maintenance procedure so that contaminants do not enter the hydraulic system.

Of the above detrimental factors, gumming or sludging, and rusting can be prevented or minimized by the incorporation of certain additives in the oil. However, in developing a good hydraulic oil, many other desirable characteristics must be considered as well.

DESIRABLE PROPERTIES OF HYDRAULIC OILS

Hydraulic systems of years ago were designed to operate with water, and, in some respects, it is

a good hydraulic fluid. Water, however, has three primary disadvantages; namely, it freezes at a temperature above that often encountered in hydraulic installations; it accelerates corrosion of metal parts; and it furnishes practically no lubrication to the moving parts of pumps or controls.

These disadvantages led to the use of petroleum oils because of their availability, adaptability and cost. The principal advantage of oil is that it not only serves as a fluid for power transmission but it lubricates all moving surfaces as well.

With the advent of improved hydraulic systems operating continuously for long periods and at higher pressures, even premium grade straight mineral oils were found in some cases to be lacking in resistance to oxidation, protective ability or foaming. These undesirable characteristics of straight mineral oils were overcome, after extensive research, by the use of additives.

The development of inhibited type hydraulic oils in use today was not made over night. Such a development began in the research laboratory. Here, pertroleum chemists studied literally thousands of potential additives. The more promising of these were subjected to severe laboratory tests, and those successfully passing these were then subjected to tests in hydraulic equipment. From the inception of the idea to the development of the final product was a long and arduous process. However, only through such a procedure was the ultimate in hydraulic oils developed.

In order to define and explain the importance of the various properties of hydraulic oils, a short discussion, starting with the base oil, is given below.

Base Oil

Base oils used in the manufacture of hydraulic fluids are carefully distilled fractions of selected crudes. These fractions are refined by the best processes known to petroleum refiners for the purpose of removing undesirable constituents. The resultant oil is comparable in quality to that used for the lubrication of steam turbines. This base oil is then fortified with various inhibitors.

Additives have a remarkable effect on the "life" and other properties of hydraulic oils, as will be shown in the ensuing sections. Their presence, however, does not permit the use of inferior base oils if maximum results are desired. For this reason, all satisfactory hydraulic oils on the market today use base oils refined to a very high degree.

Oxidation Stability

The theory underlying the effectiveness of oxidation inhibitors may be outlined briefly as follows:

1. Oxygen, which is present in the oil as a result of aeration, reacts with the oil through a "chain reaction" to form undesirable sludge and acidic material.

2. In the presence of metals and water, this reaction with oxygen is accelerated or catalyzed.

3. Certain chemicals, when added to the oil, slow down oxidation by reacting with oxygen and breaking the chain reaction, and also by de-activating the metal catalysts.

A great deal of time and effort has been spent in trying to develop suitable laboratory oxidation tests which will predict the stability of oils against oxidation in actual service. Numerous such tests have been devised and many have been discarded along the way as impractical or because they definitely cannot be correlated with actual field experience.

Of interest is a general statement made in one of the ASTM publications* concerning the significance of oxidation tests at high temperatures. To quote: "For different classes of service, different types of tests have been proposed, all of the accelerated type. Some of the methods have been developed to such a degree that the results obtainable are moderately reproducible, while others have not even reached the stage of yielding concordant results in the hands of a single operator. None of these methods, whether good or poor from the point of view of laboratory technique, has been correlated with service behavior to such a degree as to make possible any agreement on a test which should be standardized for universal use".

Today, the most generally accepted laboratory oxidation test for hydraulic oils is one proposed to the American Society for Testing Materials and known as the ASTM Oxidation Test. This test has not yet been accepted as a standard test procedure by this Society because correlation with performance in the field has not been established.

In the ASTM Oxidation Test, the oil is oxidized at 203-205°F. with pure oxygen in the presence of water and a copper-iron catalyst. The "life" of the oil is arbitrarily taken as the time required for the neutralization number (a measure of the organic acidity developed through oxidation of the oil) to reach a value of 2.0. Oils considered satisfactory by this severe test should not exceed a neutralization number of 2.0 after 1,000 or more hours.

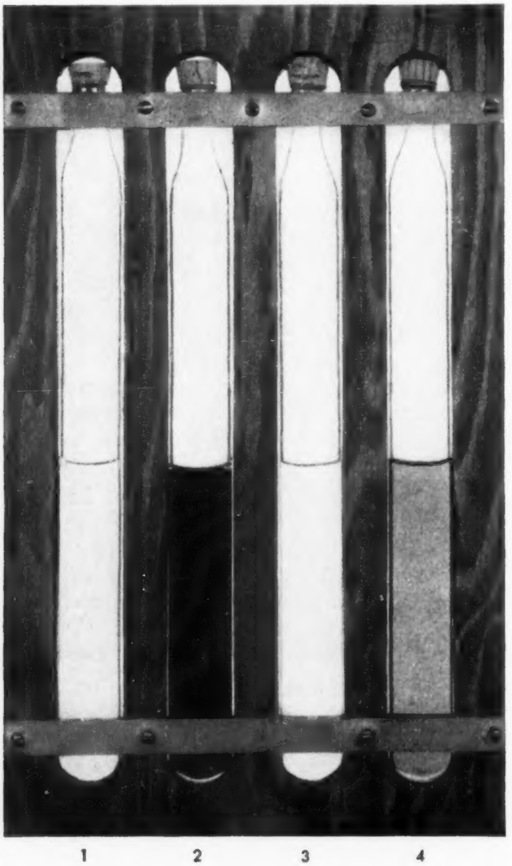
In this severe, accelerated oxidation test well-refined straight mineral oils normally take about 75 hours to reach a neutralization number of 2.0.

*The Significance of Tests of Petroleum Products, published by the American Society for Testing Materials, page 35.

With inhibited oils the number of hours required to complete the test will, of course, depend upon the efficiency of the inhibitor added. Values of 1,500 or more hours are not uncommon with oils containing oxidation inhibitors proven in service to be very effective.

Results obtained by the ASTM Oxidation Test indicate that oils containing additives to inhibit oxidation will give much longer service than straight mineral oils and this has been substantiated by field experience. Just how much longer service can be obtained in actual installations will depend upon the equipment itself, for many other factors in summation determine the actual "life" of a hydraulic oil.

There are literally hundreds of agents which can be added to oils to improve their oxidation stability and some are far more efficient than others. The ASTM Oxidation Test is a valuable research tool in weeding out the poorer of these but the only known way of proving which inhibitor is best is to run tests in actual or simulated hydraulic systems. Therefore, in selecting an inhibited type oil, choose one which has been proven in service to be highly resistant to oxidation.



1 2 3 4

Figure 4

NEW AND OXIDIZED HYDRAULIC OILS FROM A.S.T.M. OXIDATION TEST

1. New straight mineral oil of turbine grade.
2. Same oil after 72 hours. Neutralization number of straight mineral oil at this stage reached maximum allowable 2.0.
3. New oxidation inhibited hydraulic oil.
4. Same oil as shown in 3 after 1000 hours. Neutralization number at this point was 1.0.

Rust Prevention

While many theories have been advanced to explain the action of rust inhibitors, the most plausible is that the inhibitor, which has been added to the hydraulic oil, "plates out" on the metal surfaces, forming an oily film which is impervious to the rusting action of moisture and air.

Actually, the amount of rust inhibitor in the oil is only a fraction of one per cent, yet such a small amount has been proven to be sufficient to protect all metal surfaces in a hydraulic system against rust formation. No attempt has been made to measure the thickness of this effective protective layer formed, but it cannot be more than several molecules in thickness.

The generally accepted method for testing the effectiveness of such inhibitors in the laboratory is the ASTM Rusting Test.* Carefully prepared steel rods are suspended in a mixture of the oil under test containing ten per cent water which is agitated rapidly for 48 hours at a temperature of 140°F. In order for the oil to be considered satisfactory, the specimen must show no rusting at the end of the test.

The effectiveness of one rust inhibitor (let's call it inhibitor-A), as shown by results obtained on this very severe test, is illustrated by Rod 1 in Figure 5. When using an uninhibited straight mineral oil the rod rusted badly, but when a rust inhibitor was incorporated in the oil, the rod did not rust. This inhibitor has been proven in service to be extremely effective in the prevention of rust in hydraulic systems.

The fact that the protective film furnished by such an additive as inhibitor-A has great durability is shown by another laboratory test — the Shell Film Tenacity Test. In this test, a metal rod, which has shown no sign of rusting at the conclusion of the ASTM Rusting Test, is placed in a beaker containing water only. The water is agitated continuously for 24 hours at 140° F.; to pass this test the rod must show no sign of rusting. The significance of this test is that once the metal parts of a hydraulic system, whether submerged in oil or not, are coated with the inhibitor, they are impervious to water from condensation or contamination and rusting is prevented.

*American Society for Testing Materials Test No. D665-44T.

This protective film, on the other hand, can be removed by any mineral oil which is not rust inhibited, since, apparently, an equilibrium is set up between the amount of inhibitor plated out and that in the oil. For this reason if a straight mineral oil is used for makeup after an initial charge of rust inhibited oil, the effectiveness of the rust inhibitor will gradually be lost, for the "plated out" inhibitor will gradually go back into the makeup oil.

Oils containing rust inhibitors not only render protection while in the system, but are particularly effective in protecting pumps and parts during shipment or after they have just been cleaned, if coated with the inhibited oil.

Protection against rust is important even in systems where leakage is a factor to contend with. In such systems it has generally been taken for granted, in the past, that general machine oils could be used because the oil was replaced at such a rate that it did not have a chance to oxidize materially. Under such conditions even though oxidation inhibitors may not be particularly valuable, it is still economical to use oils containing rust inhibitors in systems of this type.

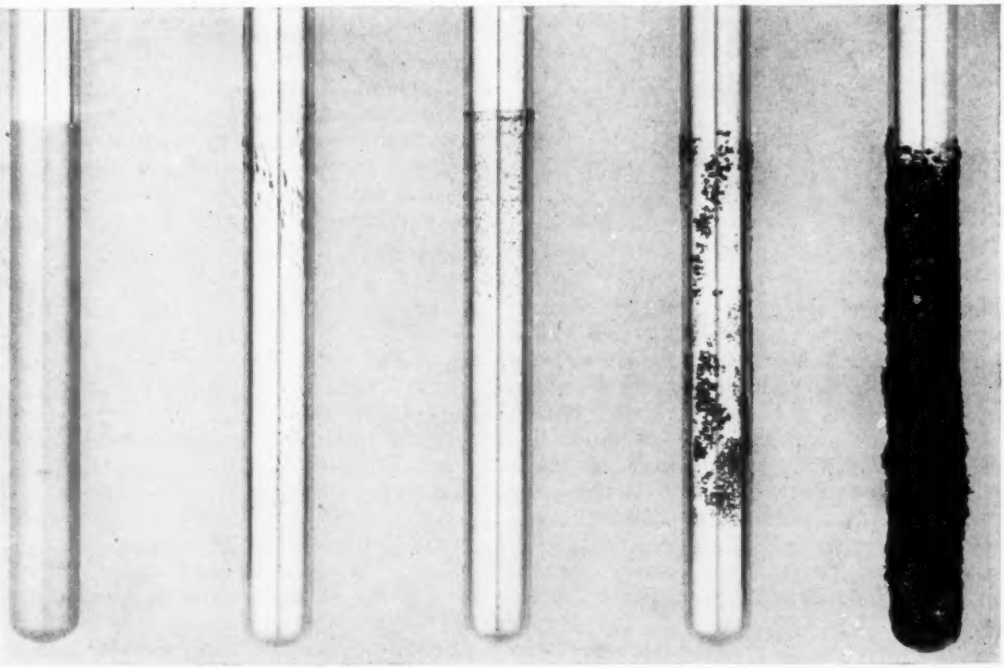
Foaming

Straight mineral oils are more or less susceptible to foaming, but petroleum chemists have found a way to so refine and treat modern hydraulic oils that if air does get into the system, it will separate quickly from the oil and can be vented off.

All mineral oils will absorb a certain amount of air depending upon the temperatures and pressures involved. For example, at atmospheric pressure and at 77°F., one gallon of oil will absorb about 10% of air by volume, but at 200 lbs. per square inch gage pressure and at 77°F., one gallon of oil will absorb about 14 times this amount of air (as measured at atmospheric pressure.) As pressure is raised, an increasing amount of air can be absorbed.

So long as air is in solution, no harm will result, but if pressure is reduced, air in the oil comes out of solution and results in foaming if the oil is not such that it will separate quickly from the air.

Foam or free air in the system is compressible, with the result that chattering or irregular motion



1 2 3 4 5

Figure 5 **STEEL RODS FROM THE A.S.T.M. RUSTING TEST**

The results above were obtained with four rust inhibited, commercially available, oils (rods 1, 2, 3, and 4) and an uninhibited straight mineral oil (rod 5). If the A.S.T.M. Rusting Test were made using distilled water mixed in with the oil, the first four rods would show no rust and the fifth rod would be about as badly rusted as shown above. The above illustrated rods were obtained after testing in various oils and synthetic sea water, a more severe test than when distilled water is used. These results show that different types of rust inhibitors offer various degrees of protection.

Results obtained on the A.S.T.M. Rusting Test clearly indicate the superior protective ability of inhibited oils over straight mineral oils.

of the moving parts will result. If the air separates quickly from the oil, the above troubles can be temporarily remedied by venting-off the free air. Foam, on the other hand, is an emulsion of air and oil and cannot be vented-off satisfactorily.

Air leaks are due entirely to mechanical causes, such as air leakage into the oil pump suction line, low oil level in the reservoir permitting the pump suction inlet to become exposed, leakage around packings, etc. It is important that the cause of air ingress be found and corrected immediately, not only because air in the system may result in erratic motion of moving parts but for another very good reason.

As mentioned before, air is compressible and anyone familiar with air compressors realizes that as air is compressed it becomes extremely hot. For example, if air is quickly compressed to 100 lbs. per sq. inch, the theoretical temperature of the air would be 485°F., and at 3,000 lbs. per sq. inch it would be 2,020°F. In a hydraulic system, if air bubbles or free air were compressed from atmospheric pressure to the above pressures, the resultant temperatures would be somewhat lower, depending upon the rate of compression, absorption into the oil, heat lost because of conduction, etc. Obviously, though, the temperature would be sufficiently high to scorch the surrounding oil, with the result that oxidation of the oil would take place. Even though heat thus generated may not be sufficient to be noticed in the overall temperature of the oil, continued oxidation of this type is cumulative and will eventually cause the entire batch of oil to become oxidized.

Viscosity

Viscosity is undoubtedly one of the most important factors to be considered in the choice of a suitable hydraulic oil. To meet the demands of the many hydraulic pump manufacturers, quite a number of grades of hydraulic oil are supplied. Each hydraulic pump, because of its design features, operates at its highest efficiency on an oil having a given viscosity. It is for this reason that hydraulic pump manufacturers issue specifications stating a limiting range of viscosities which should be used in their pumps. These viscosity specifications should be followed in selecting a suitable lubricant.

The reasons why so much importance is attached to the viscosity of oils in hydraulic systems are of considerable interest.

Of paramount importance is the fact that the viscosity must be sufficiently high to prevent wear. Practically all modern pumps will operate without excessive wear with a relatively light oil, but usually a higher viscosity oil must be used for other reasons.

In all pumps, there is a certain amount of slippage, or internal leakage of oil — that is, oil is not displaced 100% by the vanes, gears or pistons in the pumps. As the viscosity of the oil is raised, slippage will be reduced because of increased film thickness of the oil. In badly worn pumps or pumps manufactured with relatively large clearances, it is necessary to use an oil having a fairly high viscosity.

In variable displacement piston pumps, slippage can be compensated for by lengthening the stroke of the pistons. In constant delivery pumps working against a by-pass relief valve which controls the discharge pressure, the volume of oil discharged is always greater than the amount used in the system. Increased slippage in these pumps reduces the amount of oil going through the by-pass valve. As slippage is increased, however, the temperature of the oil is also increased, which is detrimental from an oxidation standpoint.

If an oil of too high a viscosity is used, the oil does not flow readily. In addition, the pressure drop through the system increases with increased viscosity which, in turn, reduces the efficiency of the system and increases power consumed in the pump.

Thus it can be seen the choice of a suitable viscosity depends on the one hand of choosing a viscosity sufficiently high to reduce wear, minimize slippage or leakage; and on the other hand using a viscosity low enough so that the oil will flow readily through the system, thus affording quick response of the moving parts and keeping power consumption at a minimum.

Effect of Temperature on Viscosity

So far the discussion of viscosity has been confined to more or less normal temperature of pump operation. Since the viscosity of oils is affected by temperature, it is important that in choosing a suitable hydraulic oil careful consideration be given to the temperature range over which the hydraulic system will operate.

At very low ambient temperatures, even oils having a low viscosity at 100°F. will have a comparatively high viscosity, as illustrated in Figure 6. This chart, incidentally, is so designed that the viscosities of a given oil at 100°F. and 210°F. can be plotted and a straight line drawn through these points. From this line then can be read the viscosity of the oil at any given temperature.

From this chart, it can be seen that an oil having a viscosity of 150 seconds at 100°F. (and a Viscosity Index of 90) would have a viscosity of about 8,000 seconds at 0°F. The latter viscosity would be the viscosity of the oil in a hydraulic system starting up at 0°F., but, of course, as the oil becomes heated during operation, its viscosity is correspondingly reduced.

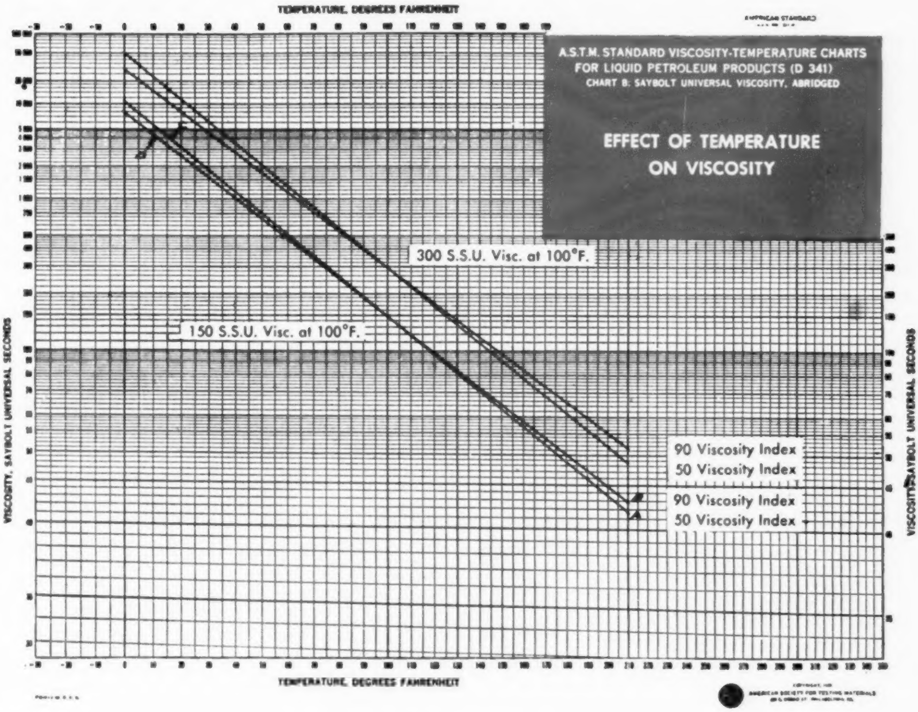


Figure 6

Several hydraulic pump manufacturers state, in their oil specifications, that the viscosity of an oil should never exceed 4,000 seconds at the lowest starting temperature. The reason for such a specification is that if an oil has a higher viscosity it will not flow readily to the pump and will be too viscous to permit quick response of moving parts. Thus, if equipment, such as construction machinery, is to be operated at very low ambient temperature, it is necessary to use an oil having a low viscosity at 100°F., or incorporate suitable heaters to raise the temperature of the oil.

Figure 6 illustrates another point often brought up in discussing hydraulic oils; namely, Viscosity Index. Viscosity Index is a numerical means of expressing the slope of lines drawn on a chart such as the one illustrated. A high Viscosity Index signifies that changes in temperature will result in a lesser change of the viscosity of the oil than that which occurs in an oil with a low Viscosity Index.

For example, Figure 6 involves four oils, two having a Viscosity Index of 50 and the other two having a Viscosity Index of 90; but for simplicity consider only the two oils having a viscosity at 100°F. of 150 seconds Saybolt Universal (S.U.S.) (Lines A & B). Line A, representing an oil having a Viscosity Index of 50, has a viscosity of 4,000 seconds at about +18°F. (Point C), whereas Line B, representing an oil having a Viscosity Index of 90, has a viscosity of 4,000 seconds at approximately +12°F. (Point D.) Thus, an improvement in Viscosity Index* of 40 points (from 50 to 90) results in a lowering of the minimum operating temperature of only 6°F. if in each case the maximum permitted viscosity does not exceed 4,000 seconds.

Oils having a high Viscosity Index are desirable because, obviously, such oils will permit easier starting at low temperatures and shorter warmup time. Conversely, they will afford better protection to moving surfaces at high operating temperatures. Mineral oils can be refined to have Viscosity Indices in the range of 80 to 100 without increasing the cost too much, and most industrial hydraulic oils on the market today fall within this range.

The Viscosity Index of an oil can also be increased by the use of additives termed Viscosity Index Improvers. Such materials as used to date are usually polymers or long chain hydrocarbons, which, it is understood, tend to break down after use at high rates of shear or under severe agitation. Additives of this type have been used in oils in hydraulic equipment exposed to much wider temperature ranges than usually encountered in industry, such as in aircraft. Undoubtedly, they will find some additional use in unusual hydraulic ap-

*For a more detailed discussion on viscosity index, see "Viscosity and Viscosity Index" Magazine Lubrication, April, 1945.

plications subjected to wide temperature variations, but normally they are not used extensively, as yet, because of their tendency to break down in severe service, and also because of their high cost.

Effect of Pressure on Viscosity

For the benefit of those who are interested in hydraulic systems operating at pressures above those normally used in most applications today the following information is presented.

Extremely high pressures have a pronounced effect on the viscosity of oils, and even pressures as high as 5,000 lbs. per sq. inch will increase the viscosity noticeably.

For example, viscosities at various pressures determined on an oil having a viscosity of 167 seconds at 100°F. Say. Univ. are shown in Table I below.*

TABLE I
EFFECT OF PRESSURE ON VISCOSITY

Pressure Lb/sq. in.	*Viscosity, Say. Univ. at 100 F.*	*210°F.*	*Viscosity Index*
Atmosphere	167	44.8	107
1,420	217	49.0	115
2,920	277	54.4	121
5,650	425	67.9	127
9,900	730	94.0	127

*From Industrial and Engineering Chemistry, Vol. 31, No. 10 (1939) p. 1267.

The above viscosities were determined at two temperatures only, but the results shown may be plotted on a standard ASTM Viscosity-Temperature Chart to give the lines shown on Figure 7 From these lines, viscosities at temperatures other than those shown in Table I can be found.

Generally, the following statements are conceded as true with respect to the effect of pressure on the viscosity of mineral oils:

1. A unit increase in pressure has more effect on viscosity at high pressures than at low pressures.

2. Increasing the pressure on an oil results in an increase in its Viscosity Index.

3. The lower the viscosity of an oil at 100°F. within the range normally used in hydraulic systems, the less effect a unit increase in pressure will have on its viscosity.

4. The viscosity of paraffin base oils is generally affected less than that of naphthenic base oils by a unit increase in pressure.

Pour Point

The pour point of an oil is defined as the temperature at which an oil ceases to pour under certain standard conditions.

All modern hydraulic oils for industrial uses have sufficiently low pour points to be fluid when used in systems located indoors and not exposed to abnormally low temperatures.

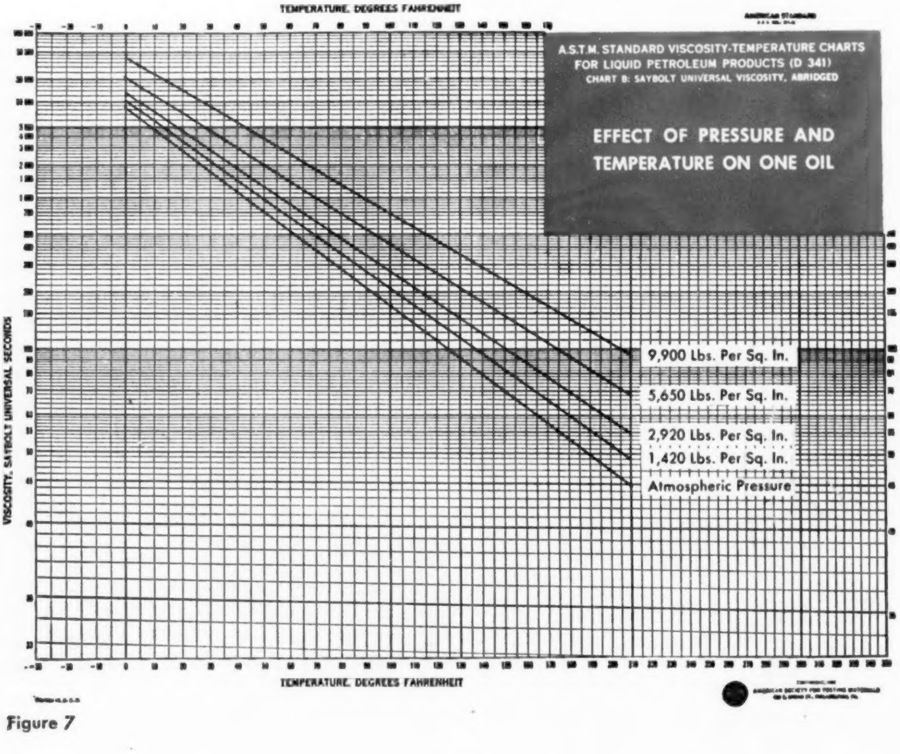


Figure 7

In systems operating out-of-doors where ambient temperatures may be very low, the pour point of the oil must be safely below the lowest temperature encountered. If it is not, wax may start to precipitate out and plug small orifices, or interfere with the smooth operation of moving parts.

It must be remembered that although a specific oil has a pour point well below a given low ambient temperature it does not mean that it is satisfactory for use. This same oil may have a viscosity at that temperature well above the maximum permitted by many pump manufacturers* and, therefore, not be able to feed properly to the pump or through the system.

CONCLUSION

Hydraulic equipment manufacturers are constantly seeking ways of making improvements, both in the design of their systems and the ever increasing scope of their application.

Constant efforts are being made to improve the metals and alloys used in hydraulic equipment, to reduce the overall size of pumps, valves and lines, and generally produce systems which are more versatile and efficient.

The field of application for hydraulics is constantly being broadened. Hydraulics are being used today in installations where the use of such a system was thought impractical only a few years ago. Examples of these are braiding or knitting machines, conveyors, bottling and filling machines, pulp grinders, centrifugals, reels and coiling machines, paper and rubber pressing machinery, printing presses, stokers, dry cleaning machines, agitators, and many, many others.

Each new development requires careful consideration of the properties of the hydraulic oils used. A few may require the use of special oils. For example, hydraulic controls are now widely used in coal mining and die-casting equipment. In these industries, consideration must be given the possibility of fires, and, as a result, work is currently being carried out to develop "fire resistant" hydraulic fluids. Synthetic non-inflammable fluids developed to date for this purpose have been considered by some to be too expensive for general use.

Petroleum technologists are keenly interested in developments taking place in the hydraulic field. Not only is such an interest necessary to keep abreast of current developments, but it is the earnest desire of the petroleum industry to furnish the best possible hydraulic oils that it is economically possible to make.

*See discussion of Viscosity, page 94.

Are Oxidation Inhibitors Really Effective?

Let's look at the record of some "bad actors" where differences in the types of oil used show up rapidly.

Case 1—Milling Machines

A midwestern auto accessory manufacturer was experiencing considerable trouble with a varnish-like product settling out of the well refined straight mineral hydraulic oil they were using in ten milling machines. Drain periods were frequent and often the hydraulic systems had to be dismantled for cleaning. Since introduction of an inhibited hydraulic oil, drain period intervals have been tripled and no deposits of any sort have been thrown out of the oil.

Case 2—Machine Tools

A machine tool manufacturer found when operating one of his machines continuously day in and day out with a turbine grade mineral oil that sludging of the hydraulic system resulted after 500-700 hours of operation. Switching to an inhibited type hydraulic oil permitted an increase between drain periods to 2400 hours with no indication of gum, varnish or sludge formation.

Case 3—Riveter

In an automotive parts manufacturing plant a hydraulically operated riveter was being operated with a well refined straight mineral oil of turbine grade and trouble with varnish formation was being experienced after thirty days of operation. Switching to an inhibited type hydraulic oil resulted in an increase between drain periods to 60 days with no indication of varnish formation.

Case 4—Broaching Machine

The hydraulic system of one broaching machine operating 22 hours a day, continuously had to be dismantled every two weeks to clean rust and deposits from pistons and valves in order to get the machine to run smoothly and with the proper speed. After switching to an inhibited type hydraulic oil the same machine ran for 90 days between drain periods with no indication of trouble.

Case 5—Grinders

An Eastern manufacturer of hydraulically operated grinders found that straight mineral oils should be changed every three months. Tests on inhibited type hydraulic oils showed that the interval between drain periods could be extended to one year.

Maintenance Suggestions

Oil Draining Schedule

The use of oils inhibited against oxidation will greatly increase the interval between draining periods provided contamination from outside the system is not a serious factor. Therefore, in order to obtain maximum use from the hydraulic oil being used definite draining schedules should be established. Since many factors affect the "life" of an oil, each machine should be checked separately to determine its draining period.

System Cleaning

Systems which have accumulated sufficient deposits to interfere with the operation of the machine can be divided into two classes; namely, those which can be flushed with light mineral oils, and those requiring more drastic action.

If a light oil can be used, the type of oil and flushing procedure must be selected to suit local conditions. Flushing oil containing a rust inhibitor is particularly advantageous because it protects metal surfaces against rust formation after draining out the hot flushing oil.

Systems sludged up sufficiently so that they cannot be cleaned with a flushing oil should be dismantled and cleaned mechanically. Known solvents and chemical cleaners on the market today are not recommended for use in hydraulic systems for several good reasons. Among these is the fact that some do not offer sufficient lubricating value with the result that moving parts are damaged. A second reason is that it is very difficult to remove all the solvent or cleaner from the system and any remaining will dilute the fresh hydraulic oil, form gummy deposits or difficult emulsions.

If rags are used to clean out the inside of a system they should be clean and lint free. The use of waste or unsuitable rags which may leave threads or lint to stick closely fitted moving parts should be avoided.

Oil Temperature

The temperature of the oil in a hydraulic system should be kept below about 140°-160°F. if possible, or a lower maximum temperature if so specified by the manufacturer.

There are two very good reasons for this. At temperatures above 140°F., the rate of oxidation of all oils (less with those inhibited against oxidation) becomes appreciable and rises rapidly as the temperature increases. In addition, as the temperatures increase, the viscosity of the oil is reduced, and if reduced sufficiently excessive slippage will occur.

Oil Storage and Handling

Refiners of hydraulic oils take particular care to see that no contaminant of any sort enters the oil up to the time it is delivered. The same care should be exercised after its delivery.

Dust, water, lint and, in fact, contaminants of any kind can seriously impair the action of a hydraulic system. To prevent such material from contaminating the oil, these simple rules should be observed.

1. Store drums on their sides and under cover. Water collecting on the top of a drum, if stored outside, may work through the bung seal into the oil.
2. Before opening a drum, wipe the top carefully so that no dirt can fall into the oil.
3. Inspect and clean all containers into which the oil is being drawn.
4. If oil drawn out of storage is not used immediately, keep it tightly covered.
5. Before adding oil to a hydraulic system, wipe off the filling plug and funnel with clean, lint-free rags.
6. Strainers should be used when filling reservoirs.
7. Don't forget to tightly close the reservoir.

Cleanliness is of paramount importance in hydraulic systems.

Trouble Shooting

Hydraulic mechanisms are precision units and their continued smooth operation depends on proper care. Therefore, do not neglect hydraulic systems. Keep them clean. Change the oil and oil filter (if present) at established intervals.

If improper operation does occur, the cause can generally be traced to one of the following:

1. Use of the wrong type of oil.
2. Insufficient fluid in the system.
3. Presence of air in the system.
4. Mechanical damage or structural failure.
5. Internal or external leakage.
6. Dirt, decomposed packing, water, sludge, rust, etc., in the system.
7. Improper adjustments.
8. Oil cooler plugged or dirty.

Possible causes of specific troubles are indicated below.

Failure of Pump to Deliver Flow

1. Low fluid level in reservoir.
2. Pressure and supply lines reversed, or motor direction reversed.
3. Pump drive shaft key sheared.
4. Intake valves plugged.
5. Air leak in suction line.
6. Pump shaft turning too slowly to prime itself.
7. Oil viscosity too heavy to pick up prime.

Loss of System Pressure

1. Pump not delivering oil for any of above reasons.
2. Low fluid level in reservoir.
3. Excessive leakage, internal or external.
   a. Regulator stuck in the cut-out position.
   b. Relief valves unseated by foreign particles.
   c. Leakage at poppets in selector valves.
   d. Pump failure.
   e. Leaky check valve in pressure regulator.
   f. Use of oil having wrong viscosity at operating temperature.
4. Pump not developing pressure.

Pump Chatter

This is caused by any condition which limits the flow of oil into the suction side of the pump. Possible causes are:

1. Plugged inlet screen.
2. Air leaking into suction side.
3. Sticking of vanes in vane type pumps.
4. Use of an oil having too high a viscosity (particularly true at low temperature.)
5. Worn pump.
6. Relief valve chattering.
7. Coupling misalignment.
8. Pump running too fast.

Excessive Heating

1. Pump discharging at a higher pressure than necessary.
   a. Excess oil dissipated through increased slippage in various parts, or through relief valve, or through throttle valves.
2. Internal oil leakage due to wear.
3. Viscosity of oil too high.
4. Pumps assembled after overhaul may be assembled too tightly, thus reducing clearances and increasing rubbing friction.
5. Leaking check valves or relief valves in pump.
6. Improper functioning of oil cooler or water to cooler is cut off.

Printed in U.S.A. by
Salley & Collins, Inc.
305 East 45th St.
New York 17, N. Y.

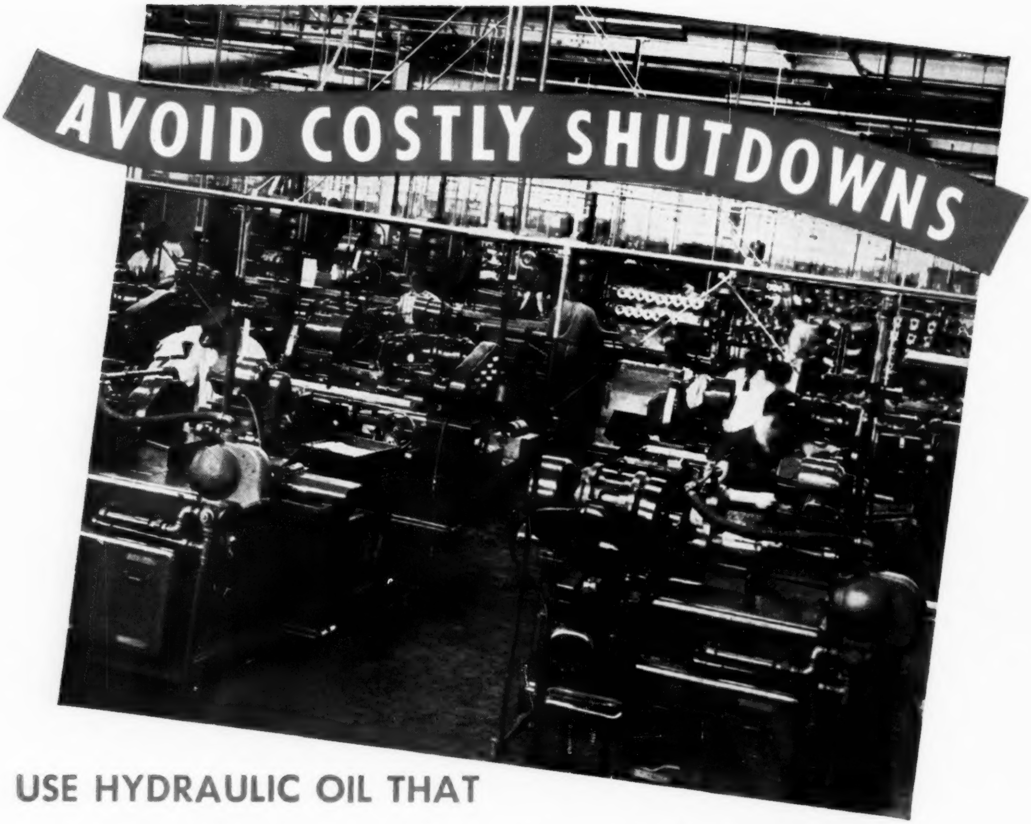
TEXACO OILS FOR

PUMP MANUFACTURER	LUBRICANT
American Engineering Co.	
(Hele-Shaw)	
Pressure up to 1500 lbs./sq. in.	Texaco Regal Oil F (R&O)
Pressure from 1500 to 3000 lbs./sq. in.	Texaco Regal Oil G (R&O)
Pressure from 1500 to 3000 lbs./sq. in. (high operating temperatures)	Texaco Regal Oil J
Brown and Sharpe Mfg. Co.	Texaco Regal Oil A (R&O)
Denison Engineering Co.	
Light	Texaco Regal Oil A (R&O) or B (R&O)
Medium	Texaco Regal Oil PC (R&O)
Medium Heavy	Texaco Regal Oil PE (R&O)
Heavy	Texaco Regal Oil F (R&O)
John S. Barnes Co.	Texaco Regal Oil A (R&O)
Gerotor May Corp.	Texaco Regal Oil PC (R&O)
Hydro Powers Inc.	Texaco Regal Oil G (R&O)
Logansport Machine Co.	
Fine metering applications	Texaco Regal Oil A (R&O)
Average operating conditions	Texaco Regal Oil B (R&O)
Heavy duty service	Texaco Regal Oil PC (R&O)
New York Air Brake Co.	Texaco Regal Oil B (R&O)
Northern Pump Co.	
Series 4300	Texaco Regal Oil C (R&O) or PC (R&O)
Series 4400, 4500, 4600, 4700, 4800	Texaco Regal Oil E (R&O) or PE (R&O)
Series 5000	Texaco Regal Oil G (R&O)
The Oilgear Co.	
2 HP. to and including 60 HP. Units of the "C" and "D" types	
40°F. to 160°F.	Texaco Regal Oil PC (R&O)
25°F. to 135°F.	Texaco Regal Oil A (R&O)
100 HP. and 150 HP. Units of the "C" and "D" types	
55°F. to 140°F.	Texaco Regal Oil PE (R&O)
40°F. to 140°F.	Texaco Regal Oil PC (R&O)
25°F. to 115°F.	Texaco Regal Oil A (R&O)
Type F Feed Pumps	
55°F. to 170°F.	Texaco Regal Oil PE (R&O)
40°F. to 170°F.	Texaco Regal Oil PC (R&O)
25°F. to 145°F.	Texaco Regal Oil A (R&O)
Racine Tool and Machine Co.	Texaco Regal Oil B (R&O)

PUMP MANUFACTURER	LUBRICANT
Simplex Engineering Co.	
(Seco Pumps)	Texaco Regal Oil B (R&O)
Sundstrand Machine Tool Co.	
Hydraulic transmissions, piston-type pumps and fluid motors	Texaco Regal Oil C (R&O) or PC (R&O)
Hydraulic circuits, PW and PWX pumps and controls	Texaco Regal Oil A (R&O)
Superdraulic Corporation	Texaco Regal Oil A (R&O)
Vickers Inc.	
Machine and Press Installations	
Vane pump installations	
Average conditions	
With flow control valves	Texaco Regal Oil A (R&O)
W/O flow control valves	Texaco Regal Oil B (R&O)
With Vickers fluid motors	Texaco Regal Oil B (R&O)
Low pressure conditions (below 500 lbs./sq. in.)	
With flow control valves	Texaco Regal Oil AA (R&O)
W/O flow control valves	Texaco Regal Oil A (R&O)
With Vickers fluid motors	Texaco Regal Oil B (R&O)
Piston pumps or piston type hydraulic transmissions	
Average conditions	Texaco Regal Oil PC (R&O)
Low pressure conditions (below 500 lbs./sq. in.)	Texaco Regal Oil B (R&O)
Mobile Machine & Outside Installations	
Vane type pumps	
Oil temperature range	
60°F. to 155°F.	Texaco Regal Oil PC (R&O)
25°F. to 145°F.	Texaco Regal Oil AZ (R&O)
–20°F. to 110°F.	Texaco Regal Oil AA (R&O)
–35°F. to 100°F.	(See footnote 1)
Piston type units	
Oil temperature range	
60°F. to 155°F.	Texaco Regal Oil PC (R&O)
25°F. to 145°F.	Texaco Regal Oil C (R&O)
–20°F. to 110°F.	Texaco Regal Oil AZ (R&O)
–35°F. to 110°F.	Texaco Regal Oil AA (R&O)

(1) Use 50-50 mixture of Texaco Regal Oil A (R&O) or Texaco Regal Oil B (R&O) with Texaco Crystalite.

Waterbury Tool Co.	Texaco Regal Oil PC (R&O)



USE HYDRAULIC OIL THAT

Prevents Rust and Sludge

KEEP your hydraulic mechanisms running smoothly and dependably with *Texaco Regal Oils (R & O)* — developed especially to 1) provide an ideal medium for transmitting power, 2) lubricate internal moving parts, and 3) prevent oxidation and corrosion.

Texaco Regal Oils (R & O) prevent oxidation which is the cause of harmful sludge. They prevent rust by "plating" internal metal parts so that moisture cannot reach them. Furthermore, *Texaco Regal Oils (R & O)* do not foam. They resist the effects of high temperature and agitation, and keep wear at a minimum.

From the biggest hydraulically operated presses to the smallest, *Texaco Regal Oils (R & O)* have proved their ability to assure smooth, dependable operation. Leading makers of hydraulically operated equipment ship them with *Texaco Regal Oils (R & O)* or recommend their use.

Texaco Regal Oils (R & O) come in sealed drums, in a range to meet every requirement. Call the nearest of the more than 2300 Texaco distributing plants in the 48 States, or write:

☆ ☆ ☆

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

THE TEXAS COMPANY • TEXACO PRODUCTS • DIVISION OFFICES

ATLANTA 1, GA. . . . 133 Carnegie Way
BOSTON 17, MASS. . 20 Providence Street
BUFFALO 3, N. Y. . . 14 Lafayette Square
BUTTE, MONT. . . Main Street & Broadway
CHICAGO 4, ILL. . 332 So. Michigan Avenue
DALLAS 2, TEX. . . 2310 So. Lamar Street
DENVER 1, COLO. . . . . 910 16th Street
HOUSTON 1, TEX. . . 720 San Jacinto Street
INDIANAPOLIS 1, IND., 3521 E. Michigan Street
LOS ANGELES 15, CAL. . 929 South Broadway
MINNEAPOLIS 2, MINN. . 300 Baker Bldg.
NEW ORLEANS 6, LA., 919 St. Charles Street
NEW YORK 17, N. Y. . 205 East 42nd Street
NORFOLK 1, VA. . Olney Rd. & Granby St.
SEATTLE 11, WASH. . . 1511 Third Avenue

Texaco Products distributed throughout Canada by McColl-Frontenac Oil Company, Limited, MONTREAL, CANADA